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Structural Integrity and Fire Resistance Performance of Lightweight Foamed Concrete Panel System

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ABSTRACT

From the experimental verification, as expected the mechanical properties of foamcrete were reasonably low when compared to normal weight concrete. Nonetheless there was a potential of using foamcrete as fire resistant partition or as load-bearing walls in low-rise residential construction. In order to demonstrate the feasibility of this proposal, this paper presents a preliminary feasibility study on its fire resistance and structural performance of foamcrete based system. The objectives of this feasibility study are tp investigate the fire resistance performance of foamcrete panels of different densities (650, 800, 1000, 1200 and 1400 kg/m^3) when exposed to fire on one side for different fire resistance ratings based on insulation requirement and to examine whether the composite walling system had sufficient load carrying capacity, based on compression resistance at ambient temperature.

Introduction

When designing a building, a very significant consideration is how it will behave in fire and ensure the elements of structure will not collapse but remain standing or hold back the fire for a prescribed time. The building regulation stipulates the rules and the degree of fire resistance of the elements of structure. For example, BS 476 (1987) dictates the appropriate fire tests for these elements of structure and materials and grades the level of fire resistance.

The author planned to develop and utilize this LFC panel system in Malaysia therefore discussion in this section will include the fire requirements stipulated in the Malaysia standard as well. All building constructions in Malaysia have to abide by the fire requirements specified in Part VII of the UBBL (1997). These requirements include the restrictions on spread of flame and fire resistance of structural members. The Ninth Schedule of the UBBL gives the minimum requirements for fire resistance (in hours) for single-storey (Part II) and multi-storey (Part I) buildings of various types. It also gave the notional fire rating values of various common types of construction. Similar fire requirements standard can also be found in other building by-laws and codes. The minimum statutory fire rating requirements for elements of structure in Malaysia and England are summarised in Table 1, for brevity and easy comparison.

Fire resistance performance of LFC panels

This section presented a limited amount of indicative study to investigate the fire resistance performance of foamcrete panels when exposed to fire on one side, based on thermal properties obtained in this study. For simplicity, the fire resistance requirement was based on thermal insulation, where the average temperature on the unexposed surface should not exceed 140^{o}C from ambient (BS476, 1987). For this predictive study, standard fire curve was used as input data and the thermal boundary condition (heat transfer coefficients) was according to EN 1991-1-2 (2004). The results were presented as the minimum thickness of the panel for the following different initial densities (kg/m^3) of foamcrete: 650, 800, 1000, 1200, 1400 and 1600. The heat transfer analysis was carried out for 30, 60, 90 and 1200 minutes of the standard fire exposure time.

Table 2 summarises the simulation results, presenting the minimum thickness of foamcrete required to achieve different fire resistance ratings for different densities. It was clear from Table 2 that as far as insulation performance was concerned, the lower the foamcrete density, the better. This was attributed to the lower thermal conductivity of lower foamcrete, as shown in Figure 1. Although Figure 1 indicated steeper upward trend in lower density foamcrete due to greater void size, less water inside lower density foamcrete would reduce the initial thermal conductivity considerably so that within the practical range of temperature, the thermal conductivity of lower density foamcrete was lower.

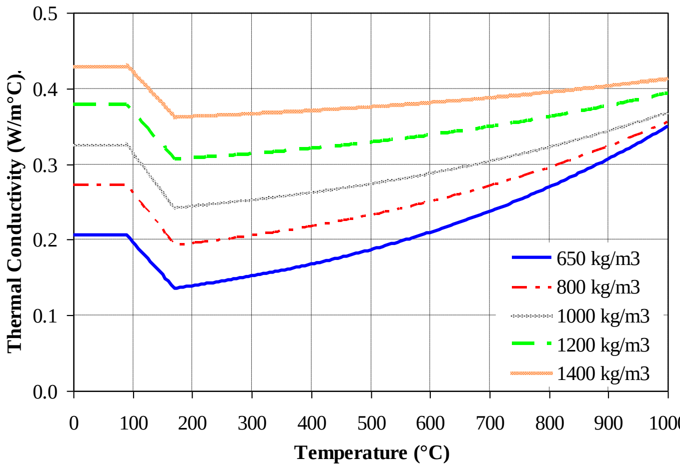

Figure 1. Thermal conductivity-temperature curves for all the densities used in this parametric study

The results in Table 2 indicated that although increasing foamcrete density would increase its specific heat, thus allowing more heat to be absorbed in foamcrete, as far as the unexposed surface temperature is concerned, which was used to assess insulation fire performance, thermal conductivity plays a more important role so that using higher density foamcrete had no advantage. The minimum thickness values in Table 2 were not

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particularly onerous. In fact, a single layer of 650 kg/m^3 density foamcrete of about 21 mm would achieve 30 minutes of standard fire resistance rating, more or less similar to gypsum plasterboard. This value is encouraging for application of foamcrete in building construction as fire resistant partitions.

From the indicative study results on foamcrete panels shown in Table 2, it can be concluded that if foamcrete panel of 100mm thickness of any density (650 to 1400 kg/m^3) was to be used in construction, it was able to meet the various fire rating requirements stipulated by the UBBL (1997) for thermal insulation. For domestic construction, a fire resistance rating of 30 minutes can be easily met by foamcrete panels.

Feasibility of using foamcrete based composite walling system

The potential market for this composite walling system is low-rise residential construction. The practicability of this system was examined by analysing the investigation to verify whether the composite walling system has sufficient load carrying capacity. It was proposed to construct the interior load-bearing walls by using 100mm thick composite walls with 0.4mm steel sheeting, as tested in this research. Figure 2 showed the elevation section of a four-storey residential building and the floor span is 5m. Table 3 summarizes the applied loads on the interior walls (panels 1-4) supporting different floors.

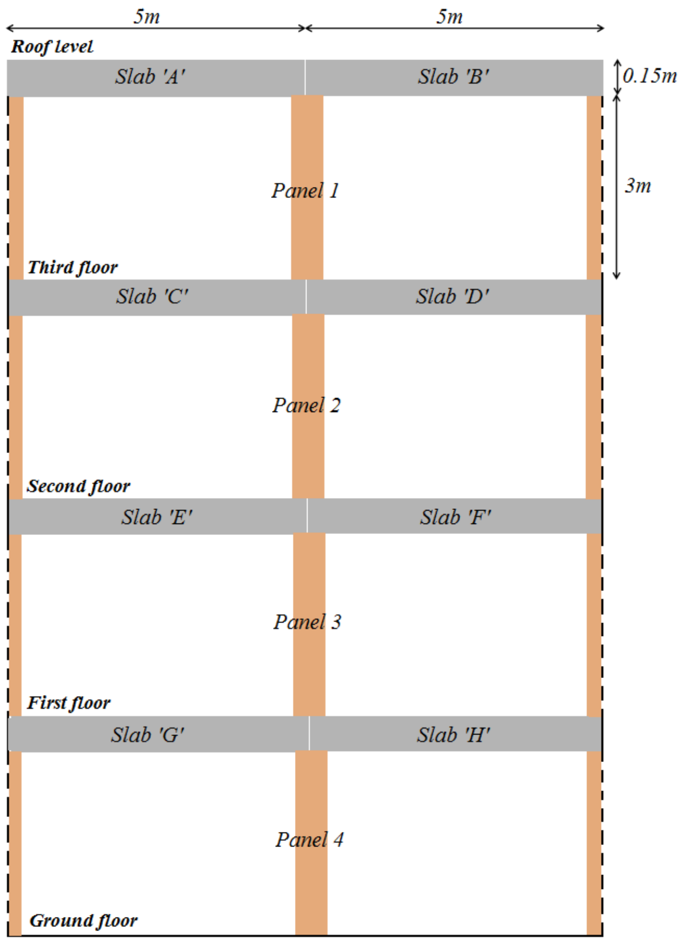

Figure 2. Arrangement of foamcrete composite wall panels for a four-storey residential building section.

Table 4 compared the applied loads (per 0.4m) on the different panels with the available panel strengths (per 0.4m) based on the experimental results obtained in this study. It was expected that the 3m wall panel as proposed in Figure 2 will have a lower strength than the 400mm high test panels due to buckling. This will be further examined in Section 4, based on flexural buckling resistance. However, the results in Table 4 clearly indicated the 100mm thick panel with 0.4mm steel sheeting has sufficient cross-sectional resistance for four floors.

Effect of slenderness ratio on load carrying capacity of composite walling system

It was expected that the strength of the proposed composite walling system will decrease increasing height due to buckling effect. The flexural buckling resistance of panel under compression may be calculated using the well known Euler equation (Gere, 2004) given below:

$$P_{cr} = \frac{\pi^2 EI}{L_p^2} \qquad \ldots\ldots(1)$$

where P_{cr} is the critical buckling load; EI ($=E_sI_s + E_cI_c$) is the flexural rigidity of the composite cross section with E_s and E_c being the Young's modulus of steel and foamcrete respectively and I_s and I_c being the second moment of area of the steel sheeting and foamcrete core respectively about the centre of the composite cross-section. E_s = 200,000 N/mm^2 and E_c = 3,300 N/mm^2. L_p is the length of composite panel.

Figure 3 clearly compared the buckling resistance of 400mm wide panels of two types of construction (with or without stopping edge) for panel heights ranging from 2m to 5m.

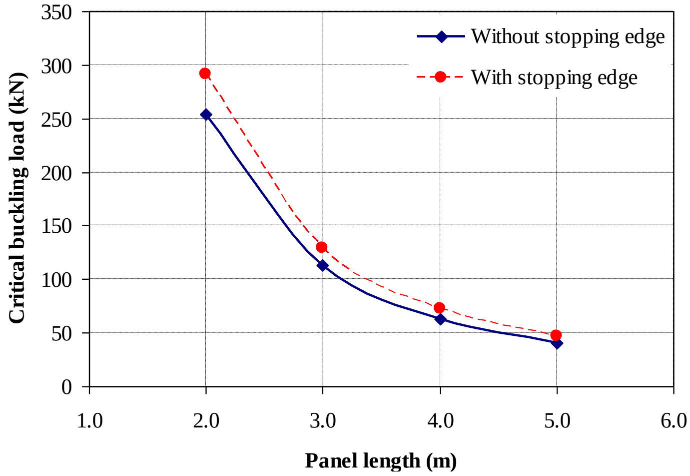

Figure 3. Relationship between critical load and panel height, panel width=400mm

Table 5 listed the applied loads (per 0.4m) for the different panels of the indicative building shown in Figure 2 with the calculated buckling strengths (per 0.4m) for different panel heights. The results showed that if the panel height does not exceed 3m, which would be sufficient to cover most cases of residential construction, the proposed panel system would have sufficient load carrying capacity. For heights of 4 and 5m, the proposed panel construction would not be sufficient for three storeys, but would be sufficient for one or two storey residential construction. For such heights, the panel thickness and steel sheeting thickness could be increased to increase the panel load carrying capacity. It should be pointed out that full composite action is not likely to take place between the steel sheeting and foamcrete core.

Interaction between the steel sheeting and the foamcrete core was generated using mechanical bolts for the samples tested in this research. Nevertheless these mechanical fasteners that connected the two profiled steel facings with the concrete core were able to give some degree of composite action and preventing the steel from peeling off during loading. It is suggested that future work is necessary to develop a better bonding system for practical application.

Table 1. Summary of minimum fire rating requirement in minutes for elements of structures in Malaysia and England (Hock and Giang, 1998)

Building category		Malaysia	England
Domestic	One storey	0	30
	2–3 Storey	30–60	30–60
Institutional	< 28 m	60–90	30–60–90
	> 28 m	90–120	120
Hotel	2 Storey	30–60	30
	3 Storey	60	60
	> 3 Storey	60–90–120	60–90–120
Office	< 7.5 m	0–30–60	30–60
	7.5–28 m	60–90	60–90
	> 28 m	60–90–120	120
Shop	< 7.5 m	0–30–60	60
	7.5–28 m	60–90	60–90
	> 28 m	60–120–240	120
Assembly	< 7.5 m	0–30–60	60
	7.5–28 m	60–90	60–90
	> 28 m	60–90–120	120
Storage	< 7.5 m	0–30–60	60–90
	7.5–15 m	30–60–120	90
	15–28 m	60–120–240	90–120
	> 28 m	240	120
Factory	< 7.5 m	0–30–60	60
	7.5–28 m	60–120–240	90–120
	> 28 m	120–240	120
Apartment	2–3 Storey	60	30
	> 3 Storey	60–90–120	60–90–120

Table 2. Indicative LFC minimum thickness for different fire resistance ratings for fire exposure from one side

Foamcrete dry density (kg/m^3)	Minimum LFC thickness (mm) for fire resistance rating of			
	30 minutes	60 minutes	90 minutes	120 minutes
650	21.0	36.7	50.1	60.5
800	22.0	38.0	51.2	61.8
1000	23.1	39.1	52.3	63.2
1200	24.0	40.0	53.0	64.2
1400	26.9	43.5	55.9	67.4

Table 3. Design of prototype composite panel

Description	Unit	Value
Slab thickness	mm	150
Dead load (partitions and finishes)	kN/m^2	1.5
Imposed loads (floor)	kN/m^2	2.5
Self weight of slab (with normal weight concrete)	kN/m	=0.15*24*5=18.0
Partition and finishes	kN/m	=5*1.5=7.5
Characteristic dead load, G_k	kN/m	=18+7.5=25.5
Characteristic imposed load, Q_k	kN/m	=5*2.5=12.5
Design load, F	kN/m	=(1.4*25.5)+(1.6*12.5)=55.7
Self weight of the panel (100 mm thick wall of 1000 kg/m^3)	kN/m	3.2
Load carried by Panel 1	kN/m	55.7
Load carried by Panel 2	kN/m	114.6
Load carried by Panel 3	kN/m	173.5
Load carried by Panel 4	kN/m	232.4

Table 4. Assessment of adequacy of 100mm thick wall with 0.4mm thick steel sheeting

Description	Required load carrying capacity per 0.4m wide (kN)	Wall adequate based on average experimental results in Table 7.2 (Chapter 7)		
		no stopping edge (165kN)	with stopping edge (181kN)	with welded stopping edge (198kN)
Panel 1	= 0.4*55.7 = 23	√	√	√
Panel 2	= 0.4*114.6 = 46	√	√	√
Panel 3	= 0.4*173.5 = 70	√	√	√
Panel 4	= 0.4*232.4 = 93	√	√	√

Table 5. Assessment of adequacy of 100mm thick wall with 0.4mm thick steel sheeting of different panel lengths

Panel length (m)		2.0	3.0	4.0	5.0
Length-width ratio		5.0	7.5	10.0	12.5
Edge condition	Required load carrying capacity per 0.4m wide	Wall adequate based on critical buckling load calculation			
No stopping edge	Panel 1 (23kN)	√	√	√	√
	Panel 2 (46kN)	√	√	√	*x*
	Panel 3 (76kN)	√	√	*x*	*x*
	Panel 4 (93kN)	√	√	*x*	*x*
With stopping edge	Panel 1 (23kN)	√	√	√	√
	Panel 2 (46kN)	√	√	√	√
	Panel 3 (76kN)	√	√	*x*	*x*
	Panel 4 (93kN)	√	√	*x*	*x*
Welded edge	Panel 1 (23kN)	√	√	√	√
	Panel 2 (46kN)	√	√	√	√
	Panel 3 (76kN)	√	√	*x*	*x*
	Panel 4 (93kN)	√	√	*x*	*x*

The main conclusion was that the foamcrete based composite walling system could be designed to resist the applied loads in low-rise residential construction.

Conclusions

This short chapter has presented the results of a feasibility study to investigate the potential of using LFC in lightweight residential construction, considering the insulation performance for fire resistance and compressive resistance of LFC wall panels at ambient temperature. From the fire resistance investigation, it had been concluded that the LFC based panel system exposed to the standard fire on one side can easily achieve the insulation performance requirement with a very small thickness, the minimum LFC panel thickness for the highest density (1400kg/m3) being around 26.9mm, 43.5mm, 55.9mm and 67.4mm for 30, 60, 90 and 120 minutes of standard fire rating respectively. This performance was very similar to that provided by gypsum plasterboards. Because of the dominant role played by thermal conductivity, lighter LFC tends to perform better because of its low thermal conductivity. From a comparison between squash resistance and Euler buckling load of LFC based composite walling systems against applied loads on a low-rise residential structure with typical floor loads and spans, it had been concluded that the LFC based walling system can be easily designed to achieve four storeys with typical floor heights between 2-5m. Although there were a number of issues should still be investigated in detail in order to fine tune the design process, this study has confirmed the applicability of LFC based panel walling system to lightweight low-rise residential construction.

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